BARIUM

FACT SHEET

See related Fact Sheets: Acronyms & Abbreviations; Glossary of Terms; Cost Assumptions; Raw Water Composition; Total Plant Costs; and WaTER Program.

1. CONTAMINANT DATA

A. Chemical Data: Barium (Ba) , atomic number: 56, atomic weight: 137.327, oxidation state: +2, metallic element, soft, and when pure is silvery white similar to lead. Occurring naturally, Ba is a mixture of seven stable isotopes. Oxidizes very easily and is decomposed by water and alcohol.

B. Source in Nature: Ba is a naturally occurring alkaline earth metal found primarily in the Midwest, in combination form with other chemicals such as sulfur or carbon and oxygen. Traces of the element are found in most surface and ground waters. It can also be produced by industry in oil and gas drilling muds, smelting of copper, waste from coal fired power plants, jet fuels, and automotive paints and accessories.

C. SDWA Limits: MCL/MCLG for Ba is 2.0 mg/L.

D. Health Effects of Contamination: The health effects of the different barium compounds depend on how well the compound dissolves in water. Ba compounds that do not dissolve well in water are not generally harmful and are often used by doctors for medical purposes. All Ba compounds that are water or acid soluble are toxic when its salts are ingested.
Ba in short-term exposures above the MCL potentially cause gastrointestinal disturbances and nerve block, causing muscular weakness. Ba in long-term exposures above the MCL have the potential to cause high blood pressure, changes in heart rhythm, brain swelling, and damage to the liver, kidney, heart, and spleen.

2. REMOVAL TECHNIQUES

A. USEPA BAT: Ion exchange, reverse osmosis, lime softening, or electrodialysis.

! IX for soluble Ba uses charged cation resin to exchange acceptable ions from the resin for undesirable forms of Ba in the water. Benefits: effective; well developed. Limitations: restocking of salt supply; regular regeneration; concentrate disposal.

! RO for soluble Ba uses a semipermeable membrane, and the application of pressure to a concentrated solution which causes water, but not suspended or dissolved solids (soluble Ba), to pass through the membrane. Benefits: produces high quality water. Limitations: cost; pretreatment/feed pump requirements; concentrate disposal.

! Lime softening for soluble Ba uses $Ca(OH)_2$ in sufficient quantity to raise the pH to about 10 to precipitate carbonate hardness and heavy metals, like Ba. Benefits: lower capital costs; proven and reliable. Limitations: operator care required with chemical usage; sludge disposal; insoluble Ba compounds may be formed at low carbonate levels requiring coagulation and flocculation.

! EDR uses semipermeable membranes in which ions migrate through the membrane from a less concentrated to a more concentrated solution as a result of the ions' representative attractions to direct electric current. Benefits: contaminant specific removal. Limitations: electrical requirements; concentrate disposal.

B. Alternative Methods of Treatment: Distillation (for home drinking water only) heats water until it turns to steam. The steam travels through a condenser coil where it is cooled and returned to liquid. The Ba remains in the boiler section. Alternately, solid block or precoated absorption filters made with carbon or activated alumina certified to reduce Ba are available.

C. Safety and Health Requirements for Treatment Processes: Personnel involved with demineralization treatment processes should be aware of the chemicals being used (MSDS information), the electrical shock hazards, and the hydraulic pressures required to operate the equipment. General industry safety, health, and self protection practices should be followed, including proper use of tools.

3. BAT PROCESS DESCRIPTION AND COST DATA

General Assumptions: Refer to: Raw Water Composition Fact Sheet for ionic concentrations; and Cost Assumptions Fact Sheet for cost index data and process assumptions. All costs are based on *ENR*, PPI, and BLS cost indices for March 2001. General sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal are not included.

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3A. Ion Exchange:

Process - In solution, salts separate into positively-charged cations and negatively-charged anions. Deionization can reduce the amounts of these ions. Cation IX is a reversible chemical process in which ions from an insoluble, permanent, solid resin bed are exchanged for ions in water. The process relies on the fact that water solutions must be electrically neutral, therefore ions in the resin bed are exchanged with ions of similar charge in the water. As a result of the exchange process, no reduction in ions is obtained. In the case of Ba reduction, operation begins with a fully recharged cation resin bed, having enough positively charged ions to carry out the cation exchange. Usually a polymer resin bed is composed of millions of medium sand grain size, spherical beads. As water passes through the resin bed, the positively charged ions are released into the water, being substituted or replaced with the Ba ions in the water (ion exchange). When the resin becomes exhausted of positively charged ions, the bed must be regenerated by passing a strong, usually NaCl (or KCl), solution over the resin bed, displacing the Ba ions with Na or K ions. Many different types of cation resins can be used to reduce dissolved Ba concentrations. The use of IX to reduce concentrations of Ba will be dependant on the specific chemical characteristics of the raw water.

Cation IX, commonly termed water softening, can be used with low flows (up to 200 GPM) and when the ratio of hardness-to-Ba is greater than 1.

Pretreatment - Guidelines are available on accepted limits for pH, organics, turbidity, and other raw water characteristics. Pretreatment may be required to reduce excessive amounts of TSS which could plug the resin bed, and typically includes media or carbon filtration.

Maintenance - The IX resin requires regular regeneration, the frequency of which depends on raw water characteristics and the Ba concentration. Preparation of the NaCl solution is required. If utilized, filter replacement and backwashing will be required.

Waste Disposal - Approval from local authorities is usually required for the disposal of concentrate from the regeneration cycle (highly concentrated alkaline solution); occasional solid wastes (in the form of broken resin beads) which are backwashed during regeneration; and if utilized, spent filters and backwash waste water.

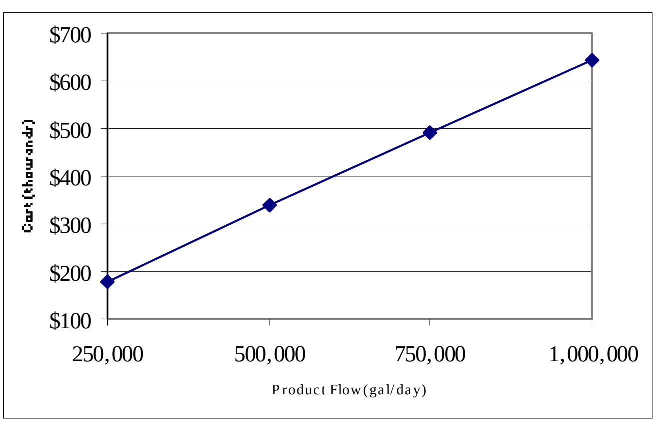
Advantages -

! Acid addition, degasification, and repressurization is not required.
! Ease of operation; highly reliable.
! Lower initial cost; resins will not wear out with regular regeneration.
! Effective; widely used.
! Suitable for small and large installations.
! Variety of specific resins are available for removing specific contaminants.

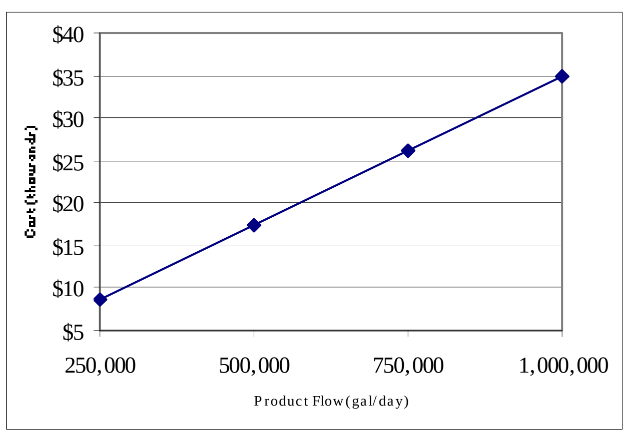
Disadvantages -

! Pretreatment lime softening may be required.
! Requires salt storage; regular regeneration.
! Concentrate disposal.
! Usually not feasible with high levels of TDS.
! Resins are sensitive to the presence of competing ions.

BAT Equipment Cost*



BAT Annual O&M Cost*



*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

3B. Reverse Osmosis:

Process - RO is a physical process in which contaminants are removed by applying pressure on the feed water to direct it through a semipermeable membrane. The process is the "reverse" of natural osmosis (water diffusion from dilute to concentrated through a semipermeable membrane to equalize ion concentration) as a result of the applied pressure to the concentrated side of the membrane, which overcomes the natural osmotic pressure. RO membranes reject ions based on size and electrical charge. The raw water is typically called feed; the product water is called permeate; and the concentrated reject is called concentrate. Common RO membrane materials include asymmetric cellulose acetate or polyamide thin film composite. Common membrane construction includes spiral wound or hollow fine fiber. Each material and construction method has specific benefits and limitations depending upon the raw water characteristics and pretreatment. A typical large RO installation includes a high pressure feed pump, parallel 1st and 2nd stage membrane elements (in pressure vessels); valving; and feed, permeate, and concentrate piping. All materials and construction methods require regular maintenance. Factors influencing membrane selection are cost, recovery, rejection, raw water characteristics, and pretreatment. Factors influencing performance are raw water characteristics, pressure, temperature, and regular monitoring and maintenance.

Pretreatment - RO requires a careful review of raw water characteristics and pretreatment needs to prevent membranes from fouling, scaling, or other membrane degradation. Removal of suspended solids is necessary to prevent colloidal and bio-fouling, and removal of dissolved solids is necessary to prevent scaling and chemical attack. Large installation pretreatment can include media filters to remove suspended particles; ion exchange softening or antiscalant to remove hardness; temperature and pH adjustment to maintain efficiency; acid to prevent scaling and membrane damage; activated carbon or bisulfite to remove chlorine (postdisinfection may be required); and cartridge (micro) filters to remove some dissolved particles and any remaining suspended particles.

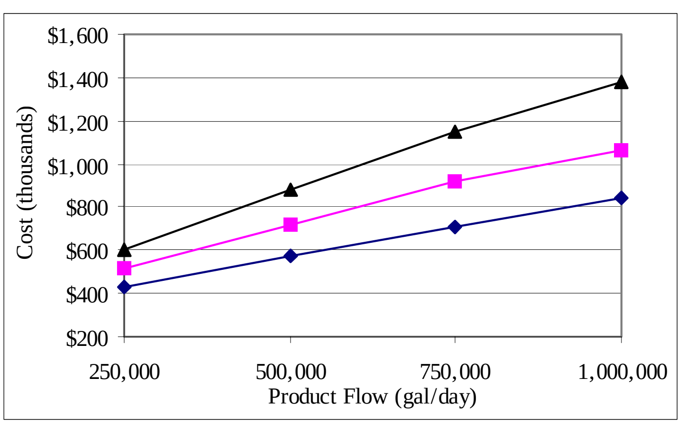
Maintenance - Monitor rejection percentage to ensure Ba removal below MCL. Regular monitoring of membrane performance is necessary to determine fouling, scaling, or other membrane degradation. Use of monitoring equations to track membrane performance is recommended. Acidic or caustic solutions are regularly flushed through the system at high volume/low pressure with a cleaning agent to remove fouling and scaling. The system is flushed and returned to service. $NaHSO_3$ is a typical caustic cleaner. RO stages are cleaned sequentially. Frequency of membrane replacement dependent on raw water characteristics, pretreatment, and maintenance.

Waste Disposal - Pretreatment waste streams, concentrate flows, and spent filters and membrane elements all require approved disposal.

Advantages -
- ! Produces highest water quality.
- ! Can effectively treat wide range of dissolved salts and minerals, turbidity, health and aesthetic contaminants, and certain organics; some highly-maintained units are capable of treating biological contaminants.
- ! Low pressure (<100 psi), compact, self-contained, single membrane units are available for small installations.

Disadvantages -
- ! Relatively expensive to install and operate.
- ! Frequent membrane monitoring and maintenance; monitoring of rejection percentage for Ba removal.
- ! Pressure, temperature, and pH requirements to meet membrane tolerances. May be chemically sensitive.

BAT Equipment Cost*



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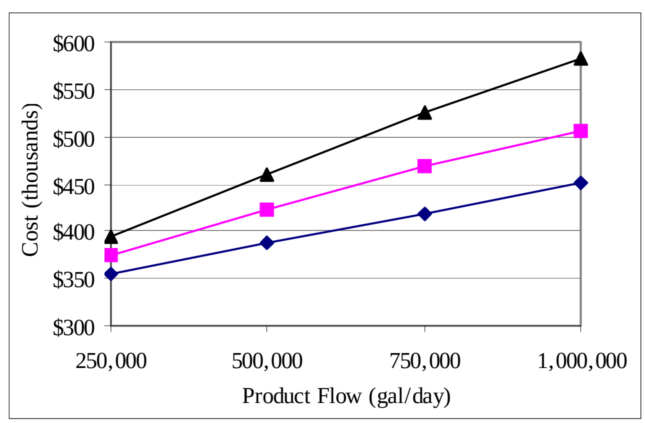
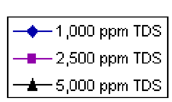




*Refer to Cost Assumptions Fact Sheet. Does not include general sitework, building, external pumps/piping, pretreatment, or off-site sludge disposal.

3C. Lime Softening:

Process - Lime softening uses a chemical addition followed by an upflow SCC to accomplish coagulation, flocculation, and clarification. Chemical addition includes adding $Ca(OH)_2$ in sufficient quantity to raise the pH while keeping the levels of alkalinity relatively low, to precipitate carbonate hardness. Heavy metals, like Ba, precipitate as $Ba(OH)_2$. In the upflow SCC, coagulation and flocculation (agglomeration of the suspended material, including Ba, into larger particles), and final clarification occur. In the upflow SCC, the clarified water flows up and over the weirs, while the settled particles are removed by pumping or other collection mechanisms (i.e. filtration).

Pretreatment - Jar tests to determine optimum pH and alkalinity for coagulation, and resulting pH and alkalinity adjustment, may be required. Optimum pH is about 10.

Maintenance - A routine check of chemical feed equipment is necessary several times during each work period to prevent clogging and equipment wear, and to ensure adequate chemical supply. All pumps, valves, and piping must be regularly checked and cleaned to prevent buildup of carbonate scale, which can cause plugging and malfunction. Similar procedures also apply to the sludge disposal return system, which takes the settled sludge from the bottom of the clarifier and conveys it to the dewatering and disposal processes.

Waste Disposal - There are three disposal options for Ba sludges: incineration, landfill, and ocean disposal. Isolation and recovery of the Ba and other economically important materials is also a viable option, however, costs of the isolation and recovery must be compared to the value of the recovered materials.

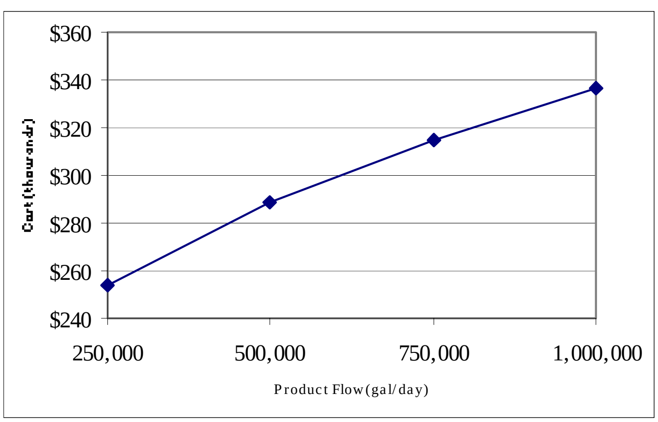
Advantages -

! Other heavy metals are also precipitated; reduces corrosion of pipes.
! Proven and reliable.
! Low pretreatment requirements.

Disadvantages -

! Excessive insoluble Ba may be formed requiring coagulation and filtration.
! Operator care required with chemical handling.
! Produces high sludge volume.

BAT Equipment Cost*



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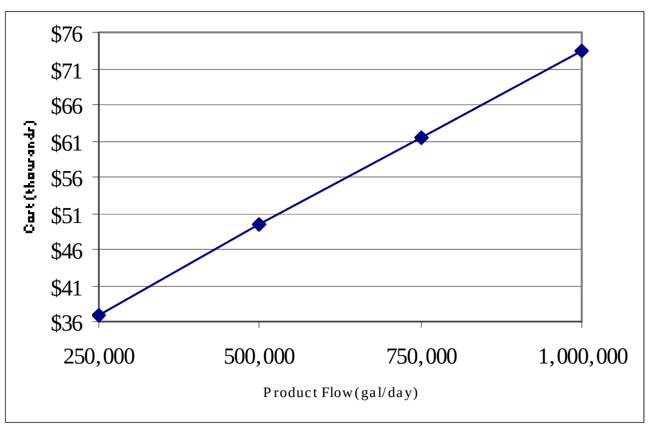

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3D. Electrodialysis Reversal:

Process - EDR is an electrochemical process in which ions migrate through ion-selective semipermeable membranes as a result of their attraction to two electrically charged electrodes. A typical EDR system includes a membrane stack with a number of cell pairs, each consisting of a cation transfer membrane, a demineralized flow spacer, an anion transfer membrane, and a concentrate flow spacer. Electrode compartments are at opposite ends of the stack. The influent feed water (chemically treated to prevent precipitation) and concentrated reject flow in parallel across the membranes and through the demineralized and concentrate flow spacers, respectively. The electrodes are continually flushed to reduce fouling or scaling. Careful consideration of flush feed water is required. Typically, the membranes are cation- or anion-exchange resins cast in sheet form; the spacers are HDPE; and the electrodes are inert metal. EDR stacks are tank contained and often staged. Membrane selection is based on careful review of raw water characteristics. A single-stage EDR system usually removes 50 percent of the TDS; therefore, for water with more than 1000 mg/L TDS, blending with higher quality water or a second stage is required to meet 500 mg/L TDS. EDR uses the technique of regularly reversing the polarity of the electrodes, thereby freeing accumulated ions on the membrane surface. This process requires additional plumbing and electrical controls, but increases membrane life, does not require added chemicals, and eases cleaning.

Pretreatment - Guidelines are available on accepted limits on pH, organics, turbidity, and other raw water characteristics. Typically requires chemical feed to prevent scaling, acid addition for pH adjustment, and a cartridge filter for prefiltration.

Maintenance - EDR membranes are durable, can tolerate pH from 1 - 10, and temperatures to 115°F for cleaning. They can be removed from the unit and scrubbed. Solids can be washed off by turning the power off and letting water circulate through the stack. Electrode washes flush out byproducts of electrode reaction. The byproducts are hydrogen, formed in the cathode space, and oxygen and chlorine gas, formed in the anode spacer. If the chlorine is not removed, toxic chlorine gas may form. Depending on raw water characteristics and Ba concentration, the membranes will require regular maintenance or replacement. EDR requires system flushes at high volume/low pressure; EDR requires reversing the polarity. Flushing is continuously required to clean electrodes. If utilized, pretreatment filter replacement and backwashing will be required.
The EDR stack must be disassembled, mechanically cleaned, and reassembled at regular intervals.

Waste Disposal - Highly concentrated reject flows, electrode cleaning flows, and spent membranes require approved disposal. Pretreatment processes and spent materials also require approved disposal.

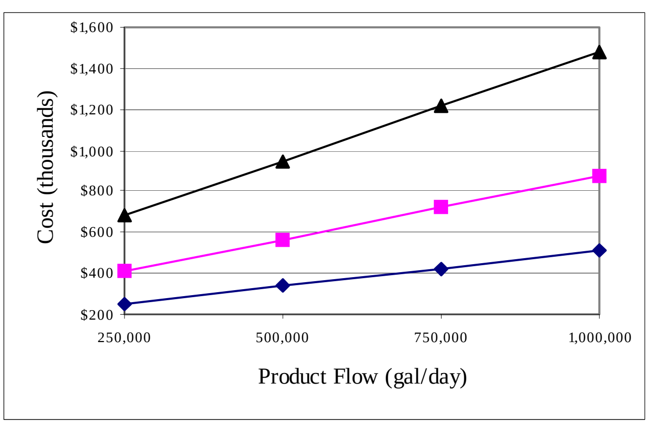
Advantages -

! EDR can operate with minimal fouling or scaling, or chemical addition.
! Low pressure requirements; typically quieter than RO.
! Long membrane life expectancy; EDR extends membrane life and reduces maintenance.

Disadvantages -

! Not suitable for high levels of Fe and Mn, H_2S, chlorine, or hardness.
! Limited current density; current leakage; back diffusion.
! At 50% rejection of TDS per pass, process favors low TDS water.

BAT Equipment Cost*



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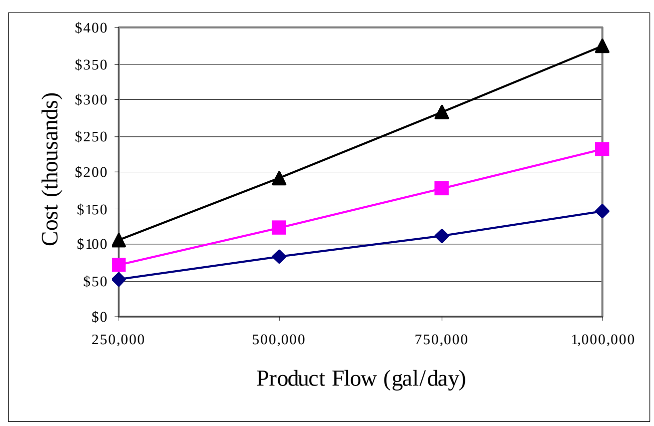

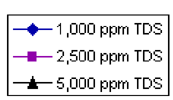

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